Top Quark Physics at DØ in Run II with 500 pb^{-1} of Data

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Top Physics Program

Production

- Top pair cross section
- o Single top cross sections
- ● Couplings: *gtt* *Wtb*
- o Spin correlations
- o $t\bar{t}$ invariant mass spectrum

Decay

- Mass m_{top}
- ● Width Γ_{top}
- ● CKM matrix element $|V_{tb}|$
- ● Gluon radiation
- ● *W* helicities
- ● Branching fractions
- ● p_T spectra
- ● Charge
- o Rare decays

● = new for Run II

o = very much improved for Run II

We think we know about m_{top} and σ, but what about ...

... All the Other Measurements

Use the reconstructed $t\bar{t}$ and single top with $t \to Wb$ for:

From σ, m_{tt} set limits on	anomalous couplings *gtt, Wtb*
	$Z', V_8, \eta_T \to t\bar{t}$; $\tilde{g} \to t\tilde{t}$; $g \to \tilde{t}\bar{\tilde{t}}$
Like sign dileptons?	$\tilde{g} \to t\tilde{t}$
Tag rate suppressed?	$t \to Ws, Wd$ $\lvert V_{tb} \rvert$ etc.
Leptonic rate enhanced?	$\tilde{t} \to bl\tilde{\nu}$
Leptonic rate suppressed?	$t \to \tilde{t}\chi^0$, $\tilde{t} \to c\chi^0$
Kinematic distribs need $m_{\text{"}\nu\text{"}}$	$t \to \tilde{t}\chi^0$, $\tilde{t} \to b\chi^+$; $\tilde{t} \to b\chi^+$
	$t \to \tilde{b}\chi^+$, $\tilde{b} \to b\chi^0$
Angular distributions	production and decay helicities

Extra particles in final state:

g, γ, b, l (one or more)	SM radiative decays, plus others

Reconstruct $t\bar{t}$ in different decay modes:

Tau rate enhanced?	$t \to H^+ b$, $H^+ \to \tau\nu$
	$t \to \tilde{t}\chi^0$, $\tilde{t} \to \tau X$ (high $\tan\beta$)
Odd stuff	$t \to \pi_T^+ b$; $t \to \tilde{t}\tilde{g}$; $t \to \tilde{t}\tilde{G}$
	$t \to \tilde{\tau}^+ b$, $\tilde{b}_\tau$ (R parity violating)
	$t \to gc, gu, \gamma c, \gamma u, Zc, Zu$ (FCNC)
	$t \to h^0 c, h^0 u, \pi_T^0 c, \pi_T^0 u$ (FCNC)

Different modes of single top production:

More odd stuff	$g, Z, \gamma \to tc, tu$; $q \to Zt, \gamma t$

Requires CAREFUL COORDINATION between Top Group and New Phenomena Group so as not to get missed.

Info from Tao Han and Regina Demina

Changes from Run I – Effect on Top

Detector Improvements

Electrons	measure p_T
	fewer fakes
	use for b tagging
Muons	better p_T
	lower minimum p_T for tags
	better η coverage
	better triggers
Jets	charge for jet ID
	b tagging with secondary vertices
	b trigger with STT

Accelerator Improvements

11% higher energy

40% increase in $t\bar{t}$ and single top cross sections

5x higher integrated luminosity

Analysis Improvements

~25x higher statistics
better MC models
better parton distribution function sets
better analysis tools
more ways to control systematic errors
more experience

Data Sets

1. **e or μ + ≥ 1 central jet**
   + $\not\!\!E_T$ for *l* +*jets/notag* background ($t\bar{t}$ and single top)
   + $\not\!\!E_T$ + ≥ 2 jets for single top
   + ‘*e*’ or ‘μ’ + ≥ 2 jets for lepton ID prob (single top)
   + ‘*e*’ or ‘μ’ + ≥ 3 jets for lepton ID prob ($t\bar{t}$)
   + *e* or μ + $\not\!\!E_T$ + ≥ 2 jets for $t\bar{t} \rightarrow dileptons$, m_{top}
   (μ) + low $\not\!\!E_T$ + ≥ 2 jets for fake μ backgd ($t\bar{t}$ and single top)
   + $\not\!\!E_T$ + ≥ 3 jets for $t\bar{t} \rightarrow lepton + jets\ /\ tag$
   + $\not\!\!E_T$ + ≥ 4 jets for $t\bar{t} \rightarrow lepton + jets\ /\ notag$, m_{top}

2. **≥ 6 jets (STT or prescaled?)**
   for $t\bar{t} \rightarrow alljets$ Xsec and m_{top}

3. ***b*-tag + ≥ 2 jets (STT)**
   $Z \rightarrow b\bar{b}$ for jet energy scale calibration
   + ≥ 3 jets to measure secondary vertex tag prob,
   fake prob (if *b*-tag is in trigger)
   + ≥ 4 jets for $single\ top \rightarrow alljets$

4. **≥ 2 jets (≥ 1 central jet; prescaled)**
   for $b\bar{b}$ continuum subtraction in energy scale calibration
   + ≥ 3 jets fake electron background in $t\bar{t}$ and single top
   and measure lepton tag rate functions
   and measure secondary vertex tag prob, fake prob
   (if *b*-tag not in trigger)

5. **Various special sets for rare decay searches**

Signal Yields in 500 pb^{-1}

Reconstructed Top Events			
Exclusive Yields (m_{top} = 175 GeV)	Run I 10% tag	Run IIa 500 pb^{-1} 45% tag	65% tag
$t\bar{t} \to ll + \geq 2 jets$	5	39	39
$t\bar{t} \to l + = 3\ jets / = 1\ tag$		17	16
$t\bar{t} \to l + = 3\ jets / = 2\ tags$		9	19
$t\bar{t} \to l + \geq 4 jets / notags$	10	178	71
$t\bar{t} \to l + \geq 4\ jets / = 1\ tag$	9	145	133
$t\bar{t} \to l + \geq 4\ jets / = 2\ tags$		70	148
$t\bar{t} \to \geq 6 jets / = 1\ tag$	14	252	232
$t\bar{t} \to \geq 6 jets / = 2\ tags$	2	124	260
Total $t\bar{t}$ Events	**40**	**834**	**918**
$t\bar{b} + \bar{t}b \to l + \geq 2 jets / notags$	~0.8	7	3
$t\bar{b} + \bar{t}b \to l + \geq 2 jets / = 1\ tag$	~0.2	11	10
$t\bar{b} + \bar{t}b \to l + \geq 2 jets / = 2\ tags$		5	10
$t\bar{b} + \bar{t}b \to \geq 4 jets / = 1\ tag$		29	27
$t\bar{b} + \bar{t}b \to \geq 4 jets / = 2\ tags$		12	25
Total s-channel single top	**~1**	**64**	**75**
$tq\bar{b} + \bar{t}\bar{q}b \to l + \geq 2 jets / notags$	~2.0	17	7
$tq\bar{b} + \bar{t}\bar{q}b \to l + \geq 2 jets / = 1\ tag$	~0.3	28	26
$tq\bar{b} + \bar{t}\bar{q}b \to l + \geq 2 jets / = 2\ tags$		11	23
$tq\bar{b} + \bar{t}\bar{q}b \to \geq 4 jets / = 1\ tag$		72	66
$tq\bar{b} + \bar{t}\bar{q}b \to \geq 4 jets / = 2\ tags$		29	61
Total t-channel single top	**~2.3**	**157**	**183**

How to Improve the Analyses

Reduce the Errors

More statistics ... the following errors will go down by $1/\sqrt{N}$:

Electron ID efficiency	5 % (CC), 7 % (EC)
Fake electron probability	10 % (CC), 8 % (EC)
Muon ID efficiency	10 % (CF), 3 % (EF)
Fake muon probability	5 % (CF), 30 % (EF)
Tag muon ID efficiency	5 % (CF), 3 % (EF)

The following errors need more work to make them go down :

Integrated luminosity	5 %
Tag rate functions	8 %
Modeling tagging muons	10 %
PDF model of proton	1 – 10 %
Jet energy scale	1 – 10 %
Multiple interactions	3 – 10 %
Modeling jets	5 – 14 %

Increase the Efficiencies / Reduce the Fake Rates

Electron ID	strongly dependent on jet multiplicity 61 % (CC), 54 % (EC), for ≥2 jet events
Fake e probability	0.01 % (CC), 0.05 % (EC)
Muon ID	~ 45 %
Fake μ probability	7 – 16 % (CF), 45 – 63 % (EF)
Jet ID	kT jets for high efficiency at low E_T ?
b-tag efficiency	10 % / jet —> 40 % – 70 % / jet ?
Fake tag prob	~ 0.4 % / jet

Improve the MC Models

Jet Modeling

$t\bar{t}$ Signal

HERWIG 5.7 and 5.9 used in Run I

Version 5.9 had a bug in the *b* parton showering
—> Too much gluon radiation at large angles. Fixed in 6.0

Version 6.1 replaces the parton showering algorithms in top decay (FSR) with NLO matrix element calculations
—> Energy radiated ~same, angular distribution different

NLO matrix elements will be in top production (ISR) soon

Single Top Signal

Get NLO generator from Laenen (extension of DYTAG)

W+Jets Background

CompHEP could replace VECBOS
—> Quark masses are included (changes pT for *b* jets)

b-Decay Modeling

Get the latest CLEO model of *b* and *c* decays for HERWIG

PDFs

Update from CTEQ3M to CTEQ6M and/or MRS98

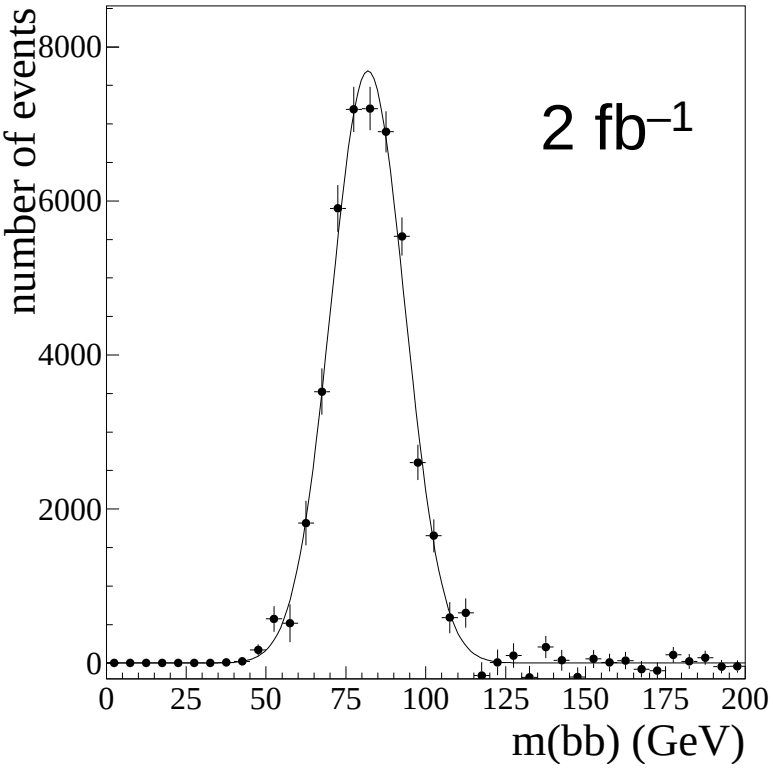
Improve the Jet Energy Scale Calibration

Narain and Heintz DØ Note 3604

Use STT with >= 2 jet events, at 20% efficiency
Able to reconstruct $Z \rightarrow b\bar{b}$ peak above 2 jet continuum

p_T balancing with dijet and $\gamma + jet$ events limited to ~1.5%
$Z \rightarrow b\bar{b}$ will reduce this to ~0.3% (Full Run II)

In 500 pb^{-1}, reconstruct ~10,000 $Z \rightarrow b\bar{b}$ on a ~140,000 $g \rightarrow b\bar{b}$ continuum



Try to do this with lepton-tagged jets too ?
Might need to if no STT. Calibrate lepton-correction to jet

Improve *b*-Tagging of Jets

Bookkeeping Problem

Run I Separate analyses for untagged and tagged events in cross section measurement

Separate treatment for untagged, single-tagged, and double-tagged events in mass measurement

Run II Each jet can have:

(SMT) (e) (μ)

(SMT+e) (SMT+μ) (e+μ) (e+e?) (μ+μ)

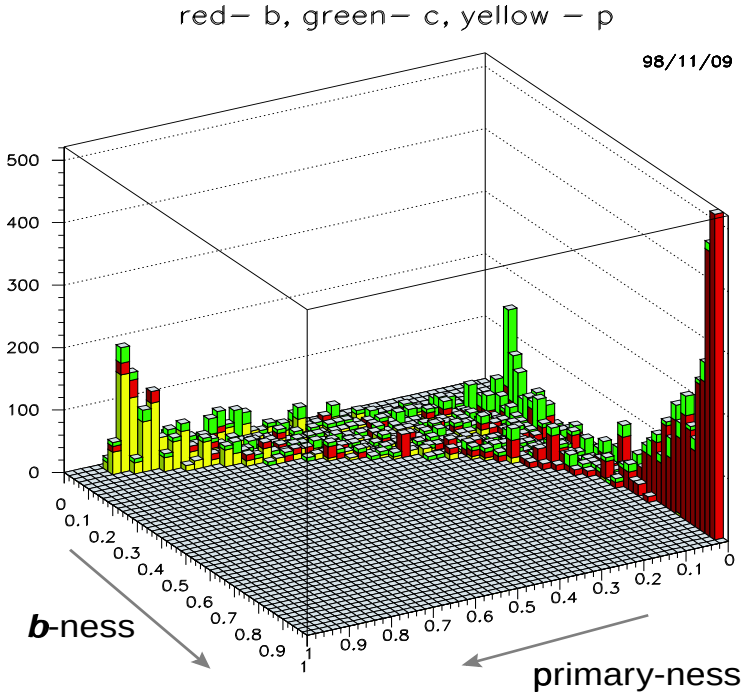
(SMT+e+μ) (SMT+e+e?) (SMT+μ+μ)

Up to two combs / event — how many analyses?

Losing Information

If the SMT, e and μ tags are just yes/no information, then much is lost – must combine all available information in NN

CDF have developed a NN with 8 inputs and 3 outputs (*b, c, p*)



(D. Amidei, R. Demina D. Wolinski)

We must do this too!
Optimized for DØ, better!

Summary of Key Issues

~ 900 $t\bar{t}$ pair events	S:B	5:1 (*ll*)	3:1 (*l*+*jets*) ?
~ 240 single top events	S:B	1:4 ?	

Yields are critically dependent on:

- keeping trigger efficiencies at Run I levels
- improving *e* ID efficiency in high occupancy environment
- improving μ ID efficiency
- using the STT for single top –> alljets

Signal:Background will be determined by:

- lowering fake rates for *e*, μ, *b*-tag
- getting high *b*-tagging efficiency

Highest quality measurements depend on:

- improving the jet energy scale calibration
- using better MC tools for modeling
- using neural networks wherever possible

Summary of Top Physics with 500 pb^{-1}

We should publish papers (PRL and/or PRD) of the following measurements:

Major:

1. top quark mass
2. $t\bar{t}$ pair production cross section
3. s-channel and t-channel single top cross sections

Production:

4. anomalous coupling limits (from cross sections)
5. gluon radiation studies
6. high mass resonance search in m_{tt}
7. spin correlations

Decay:

8. W helicities
9. branching fractions
10. p_T spectra (perhaps with 5.)

11.–15. rare searches (several)

Combined:

16. $|V_{tb}|$ and top width from single top cross section and $t\bar{t}$ decay branching fractions